Chapter 5
Conservation

Businesses are finding that by conserving natural resources and energy they can cut costs, improve the environment, and improve their competitiveness. And due to the substantial amount of rinse water consumed and wastewater generated by traditional electroless copper processes, water conservation is an issue of particular concern to printed wiring board (PWB) manufacturers and to the communities in which they are located. This chapter of the Cleaner Technologies Substitutes Assessment (CTSA) evaluates the comparative resource consumption and energy use of the making holes conductive (MHC) technologies. Section 5.1 presents a comparative analysis of the resource consumption rates of MHC technologies, including the relative amounts of rinse water consumed by the technologies and a discussion of factors affecting process and wastewater treatment chemicals consumption. Section 5.2 presents a comparative analysis of the energy impacts of MHC technologies, including the relative amount of energy consumed by each MHC process, the environmental impacts of this energy consumption, and factors affecting energy consumption during other life-cycle stages, such as chemical manufacturing or MHC waste disposal.

5.1 RESOURCE CONSERVATION

Resource conservation is an increasingly important goal for all industry sectors, particularly as global industrialization increases demand for limited resources. A PWB manufacturer can conserve resources through his or her selection of an MHC process and the manner in which it is operated. By reducing the consumption of resources, a manufacturer will not only minimize process costs and increase process efficiency, but will also conserve resources throughout the entire life-cycle chain. Resources typically consumed by the operation of the MHC process include water used for rinsing panels, process chemicals used on the process line, energy used to heat process baths and power equipment, and wastewater treatment chemicals. The focus of this section is to perform a comparative analysis of the resource consumption rates of the baseline and alternative MHC technologies. Section 5.1.1 discusses the types and quantities of natural resources (other than energy) consumed during MHC operation. Section 5.1.2 presents conclusions of this analysis.

5.1.1 Natural Resource Consumption

To determine the effects that alternatives have on the rate of natural resource consumption during the operation of the MHC process, specific data were gathered through the Performance Demonstration Project, information from chemical suppliers, and dissemination of the IPC Workplace Practices Questionnaire to industry. Natural resource data gathered through these means include the following:

- Process specifications (i.e., type of process, facility size, process throughput, etc.).
- Physical process parameters and equipment description (i.e., automation level, bath size, rinse water system configuration, pollution prevention equipment, etc.).

- Operating procedures and employee practices (i.e., process cycle-time, individual bath dwell times, bath maintenance practices, chemical disposal procedures, etc.).
- Resource consumption data (i.e., rinse water flow rates, frequency of bath replacement, criteria for replacement, bath formulations, frequency of chemical addition, etc.).

Using the collected data, a comparative analysis of the water consumption rates for each of the MHC alternatives was developed. For both process chemical and treatment chemical consumption, however, statistically meaningful conclusions could not be drawn from the compiled data. Differences in process chemicals and chemical product lines, bath maintenance practices, and process operating procedures, just to name a few possibilities, introduced enough uncertainty and variability to prevent the formulation of quantifiable conclusions. A qualitative analysis of these data is therefore presented and factors affecting the chemical consumption rates are identified. Table 5.1 summarizes the types of resources consumed during the MHC operation and the effects of the MHC alternatives on resource conservation. Water, process chemicals, and treatment chemicals consumption are discussed below.

Table 5.1 Effects of MHC Alternatives on Resource Consumption

Resource	Effects of MHC Alternative on Resource Consumption
Water	Water consumption can vary significantly according to MHC alternative and level of automation. Other factors such as water and sewage costs and operating practices also affect water consumption rates.
Process Chemicals	Reduction in the number of chemical baths comprising MHC substitutes typically leads to reduced chemical consumption. The quantity of process chemicals consumed is also dependent on other factors such as expected bath lives (e.g., the number of surface square feet (ssf) processed before a bath must be replaced or chemicals added), process throughput, and individual facility operating practices.
Energy	Energy consumption rates can differ substantially among the baseline and alternatives. Energy consumption is discussed in Section 5.2.
Treatment Chemicals	Water consumption rates and the associated quantities of wastewater generated as well as the elimination of chelators from the MHC process can result in differences in the type and quantity of treatment chemicals consumed.

Water Consumption

The MHC process line consists of a series of chemical baths which are typically separated by one, and sometimes several, water rinse steps. These water rinse steps account for virtually all of the water consumed during the operation of the MHC process. The water baths dissolve or displace residual chemicals from the panel surface, preventing contamination of subsequent baths, while creating a clean panel surface for future chemical activity. The number of rinse stages recommended by chemical suppliers for their MHC processes range from two to seven, but can actually be much higher depending on facility operating practices. The number of rinse stages reported by respondents to the IPC Workplace Practices Questionnaire ranged from two to fifteen separate water rinse stages.

The flow rate required by each individual rinse tank to fulfill its role in the process is dependent on several factors, including the time of panel submersion, the type and amount of

chemical residue to be removed, the type of agitation used in the rinse stage, and the purity of rinse water. Because proper water rinsing is critical to the MHC process, manufacturers often use more water than is required to ensure that panels are cleaned sufficiently. Other methods, such as flow control valves and sensors, are available to ensure that sufficient water is available to rinse PWB panels, while minimizing the amount of water consumed by the process.

PWB manufacturers often use multiple rinse water stages between chemical process steps to facilitate better rinsing. The first rinse stage removes the majority of residual chemicals and contaminants, while subsequent rinse stages remove any remaining chemicals. Counter-current or cascade rinse systems minimize water use by feeding the water effluent from the cleanest rinse tank, usually at the end of the cascade, into the next cleanest rinse stage, and so on, until the effluent from the most contaminated, initial rinse stage is sent for treatment or recycle. Other water reuse or recycle techniques include ion exchange, reverse osmosis, as well as reusing rinse water in other plant processes. A detailed description of methods to reduce water consumption, including methods to reuse or recycle contaminated rinse water, is presented in Chapter 6 of this CTSA.

To assess the water consumption rates of the different process alternatives, data from chemical suppliers and the IPC Workplace Practices Questionnaire were used and compared for consistency. Estimated water consumption rates for each alternative were provided by chemical suppliers for each MHC process. Consumption rates were reported for three categories of manufacturing facilities based on board surface area processed in ssf per day: small (2,000 to 6,000), medium (6,000 to 15,000), and large (15,000 +). Water consumption rates for each alternative were also calculated using data collected from the IPC Workplace Practices Questionnaire. An average water flow rate per rinse stage was calculated for both non-conveyorized (1,840 gal/day per rinse stage) and conveyorized processes (1,185 gal/day per rinse stage) from the data collected. The average flow rate was then multiplied by the number of rinse stages in the standard configuration for each process (see Section 3.1, Source Release Assessment) to generate a water consumption rate per day for each MHC alternative. The number of rinse stages in a standard configuration of an alternative, the daily rinse water flow rate calculated from the IPC Workplace Practices Questionnaire, and the daily water flow rate reported by chemical suppliers for each MHC alternative are presented in Table 5.2.

To determine the overall amount of rinse water consumed by each alternative, the rinse water flow rate in Table 5.2 was multiplied by the amount of time needed for each alternative to manufacture 350,000 ssf of board (the average MHC throughput of respondents to the IPC Workplace Practices Questionnaire). The operating time required to produce the panels was simulated using a computer model developed for each MHC alternative. For the purposes of this evaluation it was assumed that the water flow to the rinse stages was turned off during periods of MHC process shutdown (e.g., bath replacements). The results of the simulation along with a discussion of the data and parameters used to define each alternative are presented in Section 4.2, Cost Analysis. The days of MHC operation required to manufacture 350,000 ssf from the simulation, the total amount of rinse water consumed for each MHC alternative, and the water consumption per ssf of board produced are presented in Table 5.3. The amount of rinse water consumed for each alternative is also displayed in Figure 5.1.

Table 5.2 Rinse Water Flow Rates for MHC Process Alternatives

MHC Process Alternative	No. of Rinse Stages[a]	MHC Rinse Water Flow Rate (gal/day)	
		IPC Workplace Practices Questionnaire[b]	Supplier Data Sheet[c]
Electroless Copper, non-conveyorized (BASELINE)	7	12,880	5,700 - 12,500
Electroless Copper, conveyorized	7	8,300	3,840
Carbon, conveyorized	4	4,740	ND
Conductive Polymer, conveyorized	4	4,740	ND
Graphite, conveyorized	2	2,370	1,400 - 3,800
Non-Formaldehyde Electroless Copper, non-conveyorized	5	9,200	ND
Organic-Palladium, non-conveyorized	5	9,200	ND
Organic-Palladium, conveyorized	5	5,930	ND
Tin-Palladium, non-conveyorized	4	7,360	4,300 - 9,400
Tin-Palladium, conveyorized	4	4,740	2,900 - 7,200

[a] Data reflects the number of rinse stages required for the standard configuration of each MHC alternative as reported in Section 3.1, Source Release Assessment. Multiple rinse tanks in succession were considered to be cascaded and thus were counted as a single rinse stage with respect to water usage.

[b] Rinse water flow rate was calculated by averaging water flow data per stage from both questionnaire and performance demonstrations data (non-conveyorized = 1,840 gal/day per rinse stage; conveyorized = 1,185 gal/day per rinse stage) and then multiplying by the number of rinse stages in each process.

[c] Data ranges reflect estimates provided by chemical suppliers for facilities with process throughputs ranging from 2,000 to 15,000 ssf per day.

ND: No Data.

An analysis of the data shows that the type of MHC process, as well as the level of automation, have a profound effect on the amount of water that a facility will consume during normal operation of the MHC line. All of the MHC alternatives have been demonstrated to consume less water during operation than the traditional non-conveyorized electroless copper process. The reduction in water usage is primarily attributable to the decreased number of rinse stages required by many of the alternative processes and the decreased operating time required to process a set number of boards. The table also demonstrates that the conveyorized version of a process typically consumes less water during operation than the non-conveyorized version of the same process, a result attributed to the decreased number of rinse steps required and the greater efficiency of conveyorized processes. Some companies have gone a step farther by developing equipment systems that monitor water quality and usage in order to optimize water rinse performance, a pollution prevention technique recommended to reduce water consumption and, thus, wastewater generation. The actual water usage experienced by manufacturers employing such a system may be less than that calculated in Table 5.3.

Table 5.3 Total Rinse Water Consumed by MHC Process Alternatives by Board Production Rate

MHC Process Alternative	Process Operating Time[a] (days)	Rinse Water Consumed (gal/350,000 ssf)	Water Consumption Rate (gal/ssf)
Electroless Copper, non-conveyorized (BASELINE)	317.5	4.09×10^6	11.7
Electroless Copper, conveyorized	48.4	4.02×10^5	1.15
Carbon, conveyorized	95.6	4.53×10^5	1.29
Conductive Polymer, conveyorized	53.9	2.55×10^5	0.73
Graphite, conveyorized	66.1	1.57×10^5	0.45
Non-Formaldehyde Electroless Copper, conveyorized	142.8	1.31×10^6	3.74
Organic-Palladium, non-conveyorized	51.5	4.74×10^5	1.35
Organic-Palladium, conveyorized	67.0	3.97×10^5	1.13
Tin-Palladium, non-conveyorized	85.5	6.29×10^5	1.80
Tin-Palladium, conveyorized	41.8	1.98×10^5	0.57

[a] Operating time is reported in the number of days required to produce 350,000 ssf of board with a day equal to 6.8 hours of process operating time. Rinse water was assumed to be turned off during periods of process shutdown, thus the simulated operating time for each alternative was adjusted to exclude these periods of shutdown. For a more detailed description of the simulation model see Section 4.2, Cost Analysis.

Figure 5.1 Water Consumption Rates of MHC Alternatives
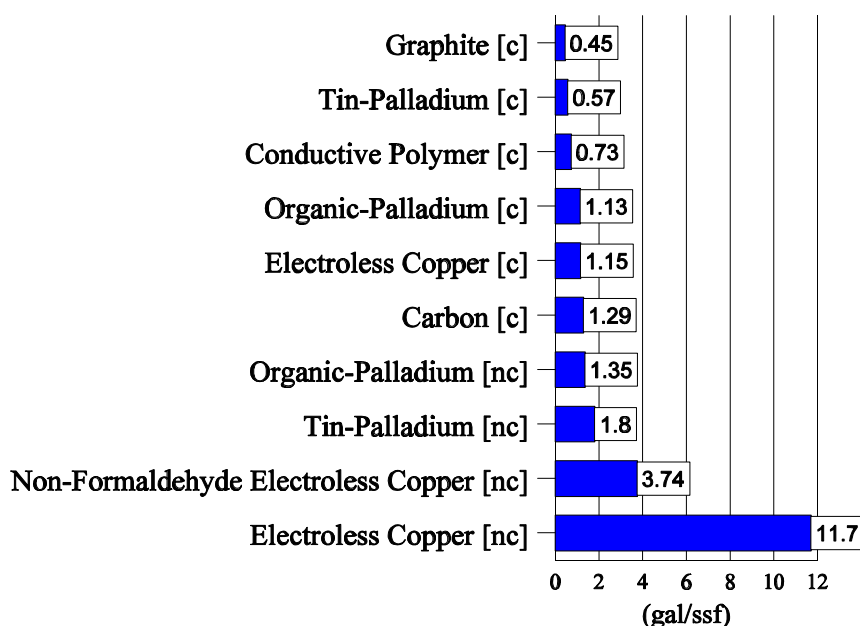
c: conveyorized
nc: non-conveyorized

A study of direct metallization processes conducted by the City of San Jose, California also identified reduced rinse water consumption as one of the many advantages of MHC alternatives (City of San Jose, 1996). The study, performed by the city's Environmental Services Department, included a literature search of currently available MHC alternatives, a survey of PWB manufacturing facilities in the area, and a comparative analysis of the advantages of MHC alternatives to electroless copper. The study report also presents several case studies of companies that have already implemented MHC alternatives. The study found that 14 out of 46 (30 percent) survey respondents cited reduced water usage as a prominent advantage of replacing their electroless copper MHC process with an alternative. On a separate survey question another five survey respondents indicated that high water use was a prominent disadvantage of operating an electroless copper MHC process. Although a couple of the companies studied reported little reduction in water usage, several other companies implementing MHC alternatives indicated decreases in water consumption. The study concluded that the magnitude of the reduction in water consumption is site-specific depending on the facility's former process set-up and operating practices.

Process Chemicals Consumption

Some of the resources consumed through the operation of the MHC process are the chemicals that comprise the various chemical baths or process steps. These chemicals are consumed through the normal operation of the MHC process line by either deposition onto the panels or degradation caused by chemical reaction. Process chemicals are also lost through volatilization, bath depletion, or contamination as PWBs are cycled through the MHC process. Process chemicals are incorporated onto the panels, lost through drag-out to the following process stages, or become contaminated through the build-up of impurities requiring the replacement of the chemical solution. Methods for limiting unnecessary chemical loss and thus minimizing the amount of chemicals consumed are presented in Chapter 6 in this CTSA.

Performing a comparative analysis of the process chemical consumption rates is difficult due to the variability and site-specific nature of many of the factors that contribute to process chemical consumption. Factors affecting the rate at which process chemicals are consumed through the operation of the MHC process include:

- Characteristics of the process chemicals (i.e., composition, concentration, volatility, etc.).
- Process operating parameters (i.e., number of chemical baths, process throughput, automation, etc.).
- Bath maintenance procedures (i.e., frequency of bath replacement, replacement criteria, frequency of chemical additions, etc.).

The chemical characteristics of the process chemicals do much to determine the rate at which chemicals are consumed in the MHC process. A chemical bath containing a highly volatile chemical or mixture of chemicals can experience significant chemical losses to the air. A more concentrated process bath will lose a greater amount of process chemicals in the same volume of drag-out than a less concentrated bath. These chemical characteristics not only vary among MHC alternatives, but can also vary considerably among MHC processes offered by different chemical suppliers within the same MHC alternative category.

The physical operating parameters of the MHC process is a primary factor affecting the consumption rate of process chemicals. One such parameter is the number of chemical baths that comprise the MHC process. Many of the MHC alternatives have reduced the number of chemical process baths, not counting rinse stages, through which a panel must be processed to perform the MHC function. The number of chemical baths in an MHC technology category range from eight for electroless copper to four in the graphite substitute. The process throughput, or quantity of PWBs being passed through the MHC process, also affects chemical usage since the higher the throughput, the more process chemicals are consumed. However, conveyorized processes tend to consume less chemicals per ssf than non-conveyorized versions of the same process due to the smaller bath sizes and higher efficiencies of the automated processes.

The greatest impact on process chemical consumption can result from the bath maintenance procedures of the facility operating the process. The frequency with which baths are replaced and the bath replacement criteria used are key chemical consumption factors. Chemical suppliers typically recommend that chemical baths be replaced using established testing criteria such as concentration thresholds of bath constituents (e.g., 2 g/L of copper content). Other bath replacement criteria include ssf of PWB processed and elapsed time since the last bath replacement. The practice of making regular adjustments to the bath chemistry through additions of process chemicals consumes process chemicals, but extends the operating life of the process baths. Despite the supplier recommendations, project data showed a wide range of bath replacement practices and criteria for manufacturing facilities operating the same, as well as different, MHC technologies.

A quantitative analysis of the consumption of process chemicals could not be performed due to the variability of factors that affect the consumption of this resource. Chemical bath concentration and composition differs significantly among MHC alternatives, but can also differ considerably among chemical product lines within an MHC alternative category. Facilities operating the same MHC alternative may have vast differences in both their MHC operating parameters and bath maintenance procedures which can vary significantly from shop-to-shop and from process-to-process. Because chemical consumption can be significantly affected by so many factors not directly attributable to the type of MHC alternative (i.e., process differences within an alternative, facility operating practices, bath maintenance procedures, etc.) it is difficult to perform any quantitative analysis of chemical consumption among alternatives. Further analysis of these issues is beyond the scope of this project and is left to future research efforts.

Wastewater Treatment Chemicals Consumption

The desire to eliminate chelating agents from the MHC process has been a factor in the movement away from electroless copper processes and toward the development of substitute MHC processes. Chelators are chemical compounds that inhibit precipitation by forming chemical complexes with metals, allowing the metals to remain soluble in solution well past their normal solubility limits. The elimination of chelating compounds from MHC wastewater greatly simplifies the chemical precipitation process required to effectively treat the streams. A detailed description of the treatment process for both chelated and non-chelated wastes, as well as a discussion of the effect of MHC alternatives on wastewater treatment, is presented in Section 6.2, Recycle, Recovery, and Control Technologies Assessment.

The extent to which the consumption of treatment chemicals will be reduced, if any, is dependant on several factors, some of which include the rate at which wastewater is generated (e.g., the amount of rinse water consumed), the type of treatment chemicals used, composition of waste streams from other plant processes, percentage of treatment plant throughput attributable to the MHC process, the resulting reduction in MHC waste volume realized, and the extent to which the former MHC process was optimized for waste reduction. Because many of the above factors are site-specific and not dependent on the type of MHC process a quantitative evaluation would not be meaningful. However, the San Jose study mentioned previously addressed this issue qualitatively.

The San Jose study found that 21 out of 46 (46 percent) survey respondents cited ease of waste treatment as a prominent advantage of MHC alternatives. In response to a separate question, 8 out of 46 (17 percent) respondents cited copper-contaminated wastewater as a prominent disadvantage of electroless copper. Most of the facilities profiled in the study reported mixed results with regard to the effects of MHC alternatives on wastewater treatment chemical usage. Although several companies reported a decrease in the amount of treatment chemicals consumed, others reported no effect or a slight increase in consumption. It was concluded that the benefits of the reduction or elimination of chelators and their impact on the consumption of treatment chemicals is site-specific (City of San Jose, 1996).

5.1.2 Conclusions

A comparative analysis of the water consumption rates was performed for the MHC process alternatives. The daily water flow rate was developed for the baseline and each alternative using survey data provided by industry. A computer simulation was used to determine the operating time required to produce 350,000 ssf of PWB for each technology and a water consumption rate was determined. Calculated water consumption rates ranged from a low of 0.45 gal/ssf for the graphite process to a high of 11.7 gal/ssf for the non-conveyorized electroless copper process. The results indicate all of the alternatives consume significantly less water than the traditional non-conveyorized electroless copper process. Conveyorized processes were found to consume less water than non-conveyorized versions of the same process.

A quantitative analysis of both process chemicals and treatment chemicals consumption could not be performed due to the variability of factors that affect the consumption of these resources. The role the MHC process has in the consumption of these resources was presented and the factors affecting the consumption rates were identified.

5.2 ENERGY IMPACTS

Energy conservation is an important goal for PWB manufacturers, as companies strive to cut costs and seek to improve environmental performance and global competitiveness. Energy use has become an important consideration in the manufacture of PWBs as much of the manufacturing process requires potentially energy-intensive operations, such as the addition of heat to process baths. This is especially true in the operation of the MHC process, where energy is consumed by immersion heaters, fluid pumps, air blowers, agitation devices such as vibrating motors, and by conveyorized transport systems. The focus of this section is to perform a comparative analysis of the relative energy consumption rates of the baseline MHC process and process alternatives and to qualitatively assess their relative energy impacts throughout the product life cycle.

Data collected for this analysis focus on the use of MHC chemical products in PWB manufacturing. Although a quantitative life-cycle analysis is beyond the scope and resources of this project, a qualitative discussion of other life-cycle stages is presented, including a discussion of the energy impacts of manufacturing or synthesizing the chemical ingredients of MHC products, as well as a discussion of the relative life-cycle environmental impacts resulting from energy consumption during the use of MHC chemicals. Section 5.2.1 discusses energy consumption during MHC process operation. Section 5.2.2 discusses the environmental impacts of this energy consumption, while Section 5.2.3 discusses energy consumption of other life-cycle stages. Section 5.2.4 presents conclusions of the comparative energy analysis.

5.2.1 Energy Consumption During MHC Process Operation

To determine the relative rates of energy consumption during the operation of the MHC technologies, specific data were collected regarding energy consumption through the Performance Demonstration project and through dissemination of the Workplace Practices Survey to industry members. Energy data collected include the following:

- Process specifications (i.e., type of process, facility size, etc.).
- Physical process parameters (i.e., number of process baths, bath size, bath conditions such as temperature and mixing, etc.).
- Process automation (i.e., conveyorized, computer-controlled hoist, manual, etc.).
- Equipment description (i.e., heater, pump, motor, etc.).
- Equipment energy specifications (i.e., electric load, duty, nominal power rating, horsepower, etc.).

Each of the MHC process alternatives consist of a series of chemical baths which are typically separated by one or more water rinse steps. In order for the process to perform properly, each chemical bath should be operated within specific supplier recommended parameters, such as parameters for bath temperature and mixing. Maintaining these chemical baths within the desired parameters often requires energy-consuming equipment such as immersion heaters, fluid circulation pumps, and air blowers. In addition, the degree of process automation affects the relative rate of energy consumption. Clearly, conveyorized equipment requires energy to operate the system, but also non-conveyorized systems require additional equipment not found in conveyorized systems, such as panel agitation equipment.

Table 5.4 lists the types of energy-consuming equipment used in MHC process lines and the function of the equipment. In some cases, one piece of equipment may be used to perform a function for the entire process line. For example, panel vibration is typically performed by a single motor used to rock an apparatus that extends over all of the process tanks. The apparatus provides agitation to each individual panel rack that is connected to it, thus requiring only a single motor to provide agitation to every bath on the process line that may require it. In other cases, each process bath or stage may require a separate piece of energy-consuming equipment.

Table 5.4 Energy-Consuming Equipment Used in MHC Process Lines

Type of Equipment	Function
Conveyor Drive Motor	Powers the conveyor system required to transport PWB panels through the MHC process.
Immersion Heater	Raise and maintain temperature of a process bath to the optimal operating temperature.
Fluid Pump	Circulate bath fluid to promote flow of bath chemicals through drilled through-holes and to assist filtering of impurities from bath chemistries.
Air Pump	Compress and blow air into process baths to promote agitation of bath to ensure chemical penetration into drilled through-holes. Also provides compressed air to processes using air knife to remove residual chemicals from PWB panels.
Panel Agitation Motor	Agitate apparatus used to gently rock panel racks back and forth in process baths. Not required for conveyorized processes.
Gas Heater	Heat PWB panels to promote drying of residual moisture remaining on the panel surface.
Ventilation Equipment	Provides ventilation required for MHC bath chemistries and to exhaust chemical fumes.

To assess the energy consumption rate of each of the MHC alternatives, an energy use profile was developed for each MHC technology that identified typical sources of energy consumption during the operation of the MHC process. The number of MHC process stages that result in the consumption of energy during their operation was determined from Performance Demonstration and Workplace Practices Survey data. This information is listed in Table 5.5 according to the function of the energy-consuming equipment. For example, a typical non-conveyorized electroless copper process consists of four heated process baths, two baths requiring fluid circulation, and a single process bath that is air sparged. The panel vibration is typically performed by a single motor used to rock an apparatus that extends over all of the process tanks. Ventilation equipment is not presented in Table 5.5 because the necessary data were not collected during the Performance Demonstration or in the Workplace Practices Survey. However, the amount of ventilation required varies according to the type of chemicals, bath operating conditions, and the configuration of the process line. Because they are enclosed, the ventilation equipment for conveyorized processes are typically more energy efficient than non-conveyorized processes.

Table 5.5 Number of MHC Process Stages that Consume Energy by Function of Equipment

Process Type	Function of Equipment[a]					
	Conveyor	Bath Heat	Fluid Circulation	Air Sparging[b]	Panel Agitation[c]	Panel Drying
Electroless Copper, non-conveyorized (BASELINE)	0	4	2	1	1	0
Electroless Copper, conveyorized	1	5	7	0	0	0
Carbon, conveyorized	1	2	6	0	0	2
Conductive Polymer, conveyorized	1	2	4	0	0	0
Graphite, conveyorized	1	1	4	0	0	1
Non-Formaldehyde Electroless Copper, non-conveyorized	0	5	2	0	1	0
Organic-Palladium, non-conveyorized	0	3	3	0	1	0
Organic-Palladium, conveyorized	1	3	7	0	0	0
Tin-Palladium, non-conveyorized	0	3	3	1	1	0
Tin-Palladium, conveyorized	1	3	9	0	0	0

[a] Table entries for each MHC alternative represent the number of process baths requiring each specific function. All functions are supplied by electric equipment, except for drying, which is performed by gas-fired oven.
[b] Air sparging is used selectively by some manufacturers to enhance bath performance. Sparging may not be required for all product lines or facilities using an alternative.
[c] Processes reporting panel agitation for one or more baths are entered as one in the summary regardless of the number since a single motor can provide agitation for the entire process line.

The electrical energy consumption of MHC line equipment as well as equipment specifications (power rating, average duty, and operating load), were collected during the Performance Demonstration. In cases where electricity consumption data were not available, the electricity consumption rate was calculated using the following equation and equipment specifications:

$$EC = NPR \times OL \times AD \times (1kW/0.746 \text{ HP})$$

where:

EC = electricity consumption rate (kWh/day)
NPR = nominal power rating (HP)
OL = operating load (%), or the percentage of the maximum load or output of the equipment that is being used
AD = average duty (h/day), or the amount of time per day that the equipment is being operated at the operating load

Electricity consumption data for each equipment category were averaged to determine the average amount of electricity consumed per hour of operation for each type of equipment per process. The natural gas consumption rate for a drying oven was supplied by an equipment vendor. Electricity and natural gas consumption rates for MHC equipment per process stage are presented in Table 5.6.

Table 5.6 Energy Consumption Rates for MHC Equipment

Function of Equipment	Type of Equipment	Energy Consumption Rates Per Process Stage	
		Electricity[a] (kW/hr)	Natural Gas[b] (ft³/hr)
Conveyorized Automation	Conveyor System	14.1	-
Non-Conveyorized Process Line[c]	Panel Agitation Motor	3.1	-
Heat	Immersion Heater	4.8	-
Fluid Circulation	Fluid Pump	0.7	-
Air Sparging	Air Pump	3.5	-
Drying Oven	Gas Heater	-	90

[a] Electricity consumption rates for each type of equipment were calculated by averaging energy consumption data per stage from the performance demonstrations. If required, consumption data were calculated from device specifications and converted to total kW/hr per bath using 1 HP = 0.746 kW.
[b] Natural gas consumption rate for the gas heater was estimated by an equipment vendor (Exair Corp.).
[c] Non-conveyorized process lines are assumed to be manually operated with no automated panel transport system. The electricity consumption rate reported includes the electricity consumed by a panel agitation motor.

The total electricity consumption rate for each MHC alternative was calculated by multiplying the number of process stages that consume electricity (Table 5.5) by the appropriate electricity consumption rate (Table 5.6) for each equipment category, then summing the results. The calculations are described by the following equation:

$$ECR_{total} = \sum_{i=1}^{n} [NPS_i \times ECR_i]$$

where:

ECR_{total} = total electricity consumption rate (kW/h)
NPS_i = number of process stages requiring equipment i
ECR_i = energy consumption rate for equipment i (kW/h)

Natural gas consumption rates were calculated using a similar method. The individual energy consumption rates for both natural gas and electricity were then converted to British Thermal Units (Btu) per hour and summed for each alternative to give the total energy consumption rate for each MHC alternative. The individual consumption rates for both natural gas and electricity, as well as the hourly energy consumption rate calculated for each of the MHC process alternatives are listed in Table 5.7.

These energy consumption rates only consider the types of equipment listed in Table 5.4, which are commonly recommended by chemical suppliers to successfully operate an MHC process. However, equipment such as ultrasonics, automated chemical feed pumps, vibration units, panel feed systems, or other types of electrically powered equipment may be part of the MHC process line. The use of this equipment may improve the performance of the MHC line, but is not required in a typical process for any of the MHC technologies.

Table 5.7 Hourly Energy Consumption Rates for MHC Alternatives

Process Type	Energy Consumption Rates		Hourly Consumption Rate[a] (Btu/hr)
	Electricity (kW/hr)	Natural Gas (ft³/hr)	
Electroless Copper, non-conveyorized (BASELINE)	27.2	-	92,830
Electroless Copper, conveyorized	43	-	146,750
Carbon, conveyorized	27.2	180	276,430
Conductive Polymer, conveyorized	26.5	-	90,440
Graphite, conveyorized	21.7	90	165,860
Non-Formaldehyde Electroless Copper, non-conveyorized	28.5	-	97,270
Organic-Palladium, non-conveyorized	19.6	-	66,890
Organic-Palladium, conveyorized	33.4	-	113,990
Tin-Palladium, non-conveyorized	23.1	-	78,840
Tin-Palladium, conveyorized	34.8	-	118,770

[a] Electrical energy was converted at the rate of 3,413 Btu per kilowatt hour where a kWh = 1 kW/hr. Natural gas consumption was converted at the rate of 1,020 Btu per cubic feet of gas consumed.

To determine the overall amount of energy consumed by each technology, the hourly energy consumption rate from Table 5.7 was multiplied by the amount of time needed for each alternative to manufacture 350,000 ssf of board (the average MHC throughput of respondents to the Workplace Practices Survey). Because insufficient survey data exist to accurately estimate the amount of time required for each process to produce the 350,000 ssf of board, the operating time was simulated using a computer model developed for each alternative. The results of the simulation along with a discussion of the data and parameters used to define each alternative are presented in Section 4.2, Cost Analysis. The hours of MHC operation required to produce 350,000 ssf of board from the simulation, the total amount of energy consumed, and the energy consumption rate for each alternative per ssf of board produced are presented in Table 5.8.

Table 5.8 shows that all of the alternatives are more energy efficient than the traditional non-conveyorized electroless copper process. This is primarily attributable to a process operating time for non-conveyorized electroless copper that is two to eight times greater than the operating times of the alternatives. Other processes with high energy consumption rates include non-formaldehyde electroless copper due to its long operating time and both carbon and graphite due to their high hourly consumption rates. The three processes consuming the least energy per unit of production are the organic-palladium non-conveyorized system and the conductive polymer and tin-palladium conveyorized systems.

The performance of specific MHC processes with respect to energy is primarily dependent on the hourly energy consumption rate (Table 5.7) and the overall operating time for the process (Table 5.8). Non-conveyorized processes typically have lower hourly consumption rates than conveyorized processes because the operation of conveyorized equipment is more energy-intensive. Although conveyorized processes typically have higher hourly consumption rates, these differences are more than offset by the shorter operating times that are required to produce an equivalent quantity of PWBs.

Table 5.8 Energy Consumption Rate per ssf of Board Produced for MHC Alternatives

Process Type	Process Operating Time[a] (hours)	Total Energy Consumed (Btu/350,000 ssf)	Energy Consumption Rate (Btu/ssf)
Electroless Copper, non-conveyorized (BASELINE)	2,160	2.01×10^8	573
Electroless Copper, conveyorized	329	4.83×10^7	138
Carbon, conveyorized	650	1.80×10^8	514
Conductive Polymer, conveyorized	367	3.31×10^7	94.7
Graphite, conveyorized	450	7.46×10^7	213
Non-Formaldehyde Electroless Copper, non-conveyorized	971	9.44×10^7	270
Organic-Palladium, non-conveyorized	350	2.34×10^7	66.9
Organic-Palladium, conveyorized	456	5.19×10^7	148
Tin-Palladium, non-conveyorized	581	4.58×10^7	131
Tin-Palladium, conveyorized	284	3.38×10^7	96.4

[a] Times listed represent the operating time required to manufacture 350,000 ssf of board by each process as simulated by computer model.

When MHC processes with both non-conveyorized and conveyorized versions are compared, the conveyorized versions of the alternatives are typically more energy efficient. Table 5.8 shows this to be true for both the electroless copper and tin-palladium processes. The organic-palladium processes are the exceptions. The non-conveyorized configuration of this process not only has a better hourly consumption rate than the conveyorized, but also benefits from a faster operating time, a condition due to the low number of process baths and its short rate-limiting step.[1] These factors combine to give the non-conveyorized organic-palladium process a lower energy consumption rate than the conveyorized version and make it the most energy efficient process evaluated.

Finally, it should be noted that the overall energy use experienced by a facility will depend greatly upon the operating practices and the energy conservation measures adopted by that facility. To minimize energy use, several simple energy conservation opportunities are available and should be implemented. These include insulating heated process baths, using thermostats on heaters, and turning off equipment when not in use.

5.2.2 Energy Consumption Environmental Impacts

The production of energy results in the release of pollution into the environment, including pollutants such as carbon dioxide (CO_2), sulfur oxides (SO_x), carbon monoxide (CO), sulfuric acid (H_2SO_4), and particulate matter. The type and quantity of pollution depends on the method of energy production. Typical energy production facilities in the U.S. include hydroelectric, nuclear, and coal-fired generating plants.

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[1] The rate-limiting step is the process step that requires more time than the other steps, thus limiting the feed rate for the system.

The environmental impacts attributable to energy production resulting from the differences in energy consumption among MHC alternatives were evaluated using a computer program developed by EPA National Risk Management Research Laboratory called *P2P- version 1.50214* (EPA, 1994). This program can, among other things, estimate the type and quantity of pollutant releases resulting from the production of energy as long as the differences in energy consumption and the source of the energy used (i.e., does the energy come from a coal-fired generating plant, or is it thermal energy from a oil-fired boiler, etc.) are known. The program uses data reflecting the "national average" pollution releases per kilowatt-hour derived from particular sources. Electrical power derived from the average national power grid was selected as the source of electrical energy, while natural gas was used as the source of thermal energy for this evaluation. Energy consumption rates from Table 5.7 were multiplied by the operating time required to produce 350,000 ssf of board reported for each alternative in Table 5.8. These totals were then divided by 350,000 to get the electrical and thermal energy consumed per ssf of board, which were then used as the basis for the analysis. Results of the environmental impact analysis from energy production have been summarized and are presented in Table 5.9. Appendix H contains printouts from the P2P program for each alternative.

Although the pollutant releases reported in Table 5.9 are combined for all media (i.e. air, water, and land), they often occur in one or more media where they may present different hazards to human health or the environment. To allow a comparison of the relative effects of any pollution that may occur, it is necessary to identify the media of releases. Table 5.10 displays the pollutants released during the production of energy, the media into which they are released, and the environmental and human health concerns associated with each pollutant.

The information presented in Tables 5.9 and 5.10 show that the generation of energy is not without environmental consequences. Pollutants released to air, water, and soil resulting from energy generation can pose direct threats to both human health and the environment. As such the consumption of energy by the MHC process contributes directly to the type and magnitude of these pollutant releases. Primary pollutants released from the production of electricity include carbon dioxide, solid wastes, sulfur oxides and nitrogen oxides. These pollutants contribute to a wide range of environmental and human health concerns. Natural gas consumption results primarily in releases of carbon dioxide and hydrocarbons which typically contribute to environmental problems such as global warming and smog. Because all of the MHC alternatives consume less energy than the traditional non-conveyorized electroless copper process, they all decrease the quantity of pollutants released into the environment resulting from the generation of the energy consumed during the MHC process.

Table 5.9 Pollution Resulting From the Generation of Energy Consumed by MHC Technologies

MHC Alternative	Types of Pollutants Released (g/ssf)[a]								
	Carbon Dioxide (CO_2)	Carbon Monoxide (CO)	Dissolved Solids	Hydrocarbons	Nitrogen Oxides (NO_x)	Particulates	Solid Wastes	Sulfur Oxides (SO_x)	Sulfuric Acid (H_2SO_4)
Electroless Copper, non-conveyorized (BASELINE)	120	0.160	0.022	0.140	0.510	0.190	14.0	1.00	0.086
Electroless Copper, conveyorized	28	0.040	0.005	0.034	0.120	0.047	3.4	0.25	0.021
Carbon, conveyorized	56	0.059	0.008	0.260	0.180	0.060	4.3	0.32	0.026
Conductive Polymer, conveyorized	19	0.027	0.004	0.024	0.084	0.032	2.3	0.17	0.014
Graphite, conveyorized	27	0.031	0.004	0.098	0.094	0.033	2.4	0.18	0.014
Non-Formaldehyde Electroless Copper, non-conveyorized	55	0.078	0.010	0.067	0.240	0.092	6.7	0.48	0.041
Organic-Palladium, non-conveyorized	14	0.019	0.003	0.017	0.060	0.023	1.7	0.12	0.010
Organic-Palladium, conveyorized	30	0.043	0.006	0.037	0.130	0.051	3.7	0.27	0.022
Tin-Palladium, non-conveyorized	27	0.038	0.005	0.033	0.120	0.045	3.2	0.23	0.020
Tin-Palladium, conveyorized	20	0.028	0.004	0.024	0.086	0.033	2.4	0.17	0.015

[a] Pollutant totals calculated using the computer program *P2P version 1.50214* developed by EPA's National Risk Management Research Laboratory.

Table 5.10 Pollutant Environmental and Human Health Concerns

Pollutant	Medium of Release	Environmental and Human Health Concerns
Carbon Dioxide (CO_2)	Air	Global warming
Carbon Monoxide (CO)	Air	Toxic organic,[a] smog
Dissolved Solids	Water	Dissolved solids[b]
Hydrocarbons	Air	Odorant, smog
Nitrogen Oxides (NO_x)	Air	Toxic inorganic,[a] acid rain, corrosive, global warming, smog
Particulates	Air	Particulates[c]
Solid Wastes	Soil	Land disposal capacity
Sulfur Oxides (SO_x)	Air	Toxic inorganic,[a] acid rain, corrosive
Sulfuric Acid (H_2SO_4)	Water	Corrosive, dissolved solids[b]

[a] Toxic organic and inorganic pollutants can result in adverse health effects in humans and wildlife.
[b] Dissolved solids are a measure of water purity and can negatively affect aquatic life as well as the future use of the water (e.g., salinity can affect the water's effectiveness at crop irrigation).
[c] Particulate releases can promote respiratory illness in humans.

5.2.3 Energy Consumption in Other Life-Cycle Stages

When performing a comparative evaluation among MHC technologies, the energy consumed throughout the entire life cycle of the chemical products in the technology should be considered. The product use phase is only one aspect of the environmental performance of a product. A life-cycle analysis considers all stages of the life of a product, beginning with the extraction of raw materials from the environment, and continuing on through the manufacture, transportation, use, recycle, and ultimate disposal of the product.

Each stage within this life cycle consumes energy. It is possible for a product to be energy efficient during the use phase of the life cycle, yet require large amounts of energy to manufacture or dispose of the product. The manufacture of graphite is an example of an energy-intensive manufacturing process. Graphite is manufactured by firing carbon black particles to temperatures over 3000 °F for several hours, which is required to give a crystalline structure to the otherwise amorphic carbon black particles (Thorn, 1996). There are also energy consumption differences in the transportation of wastes generated by an MHC line. The transportation of large quantities of sludge resulting from the treatment of processes with chelated waste streams (i.e., electroless copper) will consume more energy than the transportation of smaller quantities of sludge resulting from processes that do not use chelators. These examples show that energy use from other life-cycle stages can be significant and should be considered when evaluating the energy performance of a product. However, a comprehensive assessment of other life-cycle stages was beyond the scope of this study.

5.2.4 Conclusions

A comparative analysis of the relative energy consumption rates was performed for the MHC technologies. An hourly energy consumption rate was developed for the baseline and each alternative using data collected from industry through a survey. A computer simulation was used to determine the operating time required to produce 350,000 ssf of PWB and an energy

consumption rate per ssf of PWB was calculated. The energy consumption rates ranged from 66.9 Btu/ssf for the non-conveyorized organic-palladium process to 573 Btu/ssf for the non-conveyorized electroless copper process. The results indicate all of the MHC alternatives are more energy efficient than the traditional non-conveyorized electroless copper process. It was also found that for alternatives with both types of automation, the conveyorized version of the process is typically the more energy efficient, with the notable exception of the organic-palladium process.

An analysis of the impacts directly resulting from the production of energy consumed by the MHC process showed that the generation of the required energy is not without environmental consequence. Pollutants released to air, water, and soil can result in damage to both human health and the environment. The consumption of natural gas tends to result in releases to the air which contribute to odor, smog and global warming, while the generation of electricity can result in pollutant releases to all media with a wide range of possible affects. Since all of the MHC alternatives consume less energy than electroless copper, they all result in less pollutant releases to the environment from energy production.

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